The A. & M. College of Texas

Department of

OCEANOGRAPHY AND METEOROLOGY

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Texas A. & M. Research Foundation

COLLEGE STATION, TEXAS

RESEARCH ON TROPICAL RAINFALL PATTERNS AND ASSOCIATED MESO-SCALE SYSTEMS

Report Nr. 2

Electronics Contract Number DA-36-039 SC-89202

DEPARTMENT OF THE ARMY PROJECT Nr. 3A99-27-005-09

Second Quarterly Progress Report

1 September 1962 to 31 December 1962

A. and M. Project Nr. 311
Reference 62-21-T
25 March 1963

U. S. Army Electronics Research
and Development Laboratory,
Fort Monmouth, New Jersey

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Signal Corps Technical Guidelines for

P.R. & C. 62-ELS/R-1526 dated 20 December 1961

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The objective of this study is to obtain information on, and understanding of, meso-scale rainfall patterns in the Tropics. The work, at present, is concentrating on the Central American area.

Report Prepared by

John F. Griffiths

and

Walter K. Henry

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OBJECTIVES OF THIS RESEARCH

The objectives of this research are as follows:

A. To identify the different sub-regions of meso-scale rainfall patterns.

B. To obtain information for locating new stations which will give a better understanding of the rainfall system movements.

C. To determine orographic effects on meso-scale rainfall patterns.

D. To investigate any singularities of rainfall which are encountered in the data.

ABSTRACT

A successful data gathering trip into Central America yielded a large volume of rainfall information. This included daily, monthly, and annual data for a large number of stations. Statistical analysis of the monthly data for El Salvador has been initiated. Meso-scale analysis of daily rainfall is attempted.

LECTURES

Mr. Griffiths and Mr. Henry presented a lecture to the College Station Chapter of the American Meteorological Society.

Title: Progress and Aims of Project 311

Place: College Station, Texas

Date: December 4, 1962

REPORTS

Title: Research on Tropical Rainfall Patterns and Associated Meso-Scale System Movements. First Quarterly Progress Report, 10 September 1962, John F. Griffiths and Walter K. Henry.

CONFERENCES

On September 2, 1962, Mr. Griffiths, Mr. Cobb, and Mr. Henry departed for a two week data gathering trip to Central America. The trip was most successful. A short resume of the people visited and the data collected follows.

September 3 - San Salvador, El Salvador, Ing. Helmut Lessmann, Director Del Servicio Meteorologico Nacional. Ing. Lessmann had collected monthly and annual totals of rainfall for 130 stations for up to about 50 years. Some 45 of these stations have more than 10 years of data. He was most helpful in arranging for copies of this fine collection of data to be made available for the Project.

September 4 - Canal Zone, Mr. T. C. Henter, Hydrographic Office, Panama Canal Company; Major Kneid, Assistant Signal Officer, Caribbean Command; Major George A. Lockhart, Jr., Commander Det. 17, 15th Weather Squadron, Howard A. F. B.: Obtained monthly and annual data for 65 stations of at least 10 years duration, some stations having continuous records for 85 years. The CPS-9 radar pictures, taken at Albrook A. F. B., were made available to us, along with the daily maps. These are on a loan basis. All the persons listed above showed interest in the project and were extremely cooperative.

CONFERENCES con't.

September 5 - Puerto Armuelles, Panama, Mr. Arthur C. Hamilton, Manager, Chirique Land Company; Mr. Boyd Quate, President, Weather Engineers Inc.; Mr. Loren W. Crow, Consulting Meteorologist: Obtained daily rainfall data for a closely spaced network of rainfall gages for a period of ten years. Mr. Crow and Mr. Quate have been working on similar problems. They were able to make several suggestions.

September 6 - Golfito, Costa Rica, Mr. Cambell, Assistant Manager, Chirique Land Company: Obtained ten years of daily rainfall data for a closely spaced network of stations. These data physically join the data obtained in Puerto Armuelles and give a total of approximately 100 stations, most of which are in an area of 10 by 20 miles.

September 7 - San Jose, Costa Rica, Mr. Gronblad, Manager, Bananera De Costa Rica; Dr. Elliot Coen, Director, Servico Meteorologico Nacional. Mr. Gronblad was very helpful and able to give us monthly and daily data from Port Limon area. Dr. Coen had a good supply of data, monthly and annual for about 135 stations, many having long time continuity, but satisfactory arrangements could not be made to obtain copies.

September 10- Tegucigalpa, Honduras, Sr. Santiago Chiez, Director General de Aeronautica Civil; Sr. Vicente Fernandez, Assistant

CONFERENCES con't.

Chief, Honduranian Weather Service. The Honduranian Weather Service was well organized and was producing maps and forecasts for all of Central America. They were doing excellent synoptic meteorology. Their climatic work was limited but they had assembled good rainfall data for about 140 stations. Thirty-five of these were for periods of more than 10 years, and they were most helpful in making the data available to us.

September 11- La Ceiba, Honduras, Mr. G. T. Feyling, Manager, Standard Fruit Company; Mr. R. N. Quast, Standard Fruit Company: Obtained daily rainfall data for eight years for the Standard Fruit plantations. These data were for about 20 stations along the Aguan River Valley. The Standard Fruit Company showed their interest in our project.

September 12- La Lima, Honduras, Mr. James Shelton, Chief of Operations, Chirique Land Company; Mr. Peter Stubbe; Dr. R. H. Stover, Assistant Director, Division of Tropical Research, United Fruit Company. All of this group were very cooperative and supplied four years of daily rainfall data for some 40 stations in the Ulua River Valley and some long term monthly data.

CONFERENCES, con't.

September 13- Guatemala City, Guatemala, Sr. Carlos E. Pinto, Agent Chirique Land Company. He was most cooperative and able to give us daily rainfall data for several years in the Motagua River Valley. The three river valleys are almost parallel and when combined make an excellent set of data. The President of the Republic announced an extra holiday which precluded more extensive data gathering in Guatemala and the national services were not approached.

September 13- Belize, British Honduras, Mr. Chopin: Obtained annual and monthly data for about fifteen stations of 8 years duration.

For the excellent cooperation of the people listed above, the authors express their deep thanks. In addition, the authors wish to express their appreciation to the Standard Fruit Company, and Mr. R. A. Holcombe and Mr. Joseph W. Montgomery of the United Fruit Company.

October 9 - Mr. Griffiths and Mr. Henry visited with Dr. Wilfried Portig and Dr. John Gerhardt of the University of Texas. Discussions concerning the project were stimulating.

October 22-27 Mr. Griffiths visited our sponsor. He had beneficial discussions with Mr. Marvin Lowenthal and with Dr. R. M.

Marchgraber. On the same trip he visited the data center at Ashville to search for usable data.

December 7 - Dr. Wilfried Portig, University of Texas, visited the project. He contributed several good suggestions as well as some choice data from Panama.

The authors are indebted to Dr. Portig and the U. S. Electronics Research and Development Laboratory for the excellent card index bibliography concerning tropical meteorology.

WORK ACCOMPLISHED THIS PERIOD

A. Data Collecting and Processing

Following the successful data collecting trip to Central America described previously in this report, came the task of organizing this volume of data. Most of the efforts of the persons employed were directed toward sorting and organizing the data. Some of the data had to be returned; therefore, it had to be copied. Other data were not arranged suitably for our purposes and had to be reorganized. This type of work consumed many man hours.

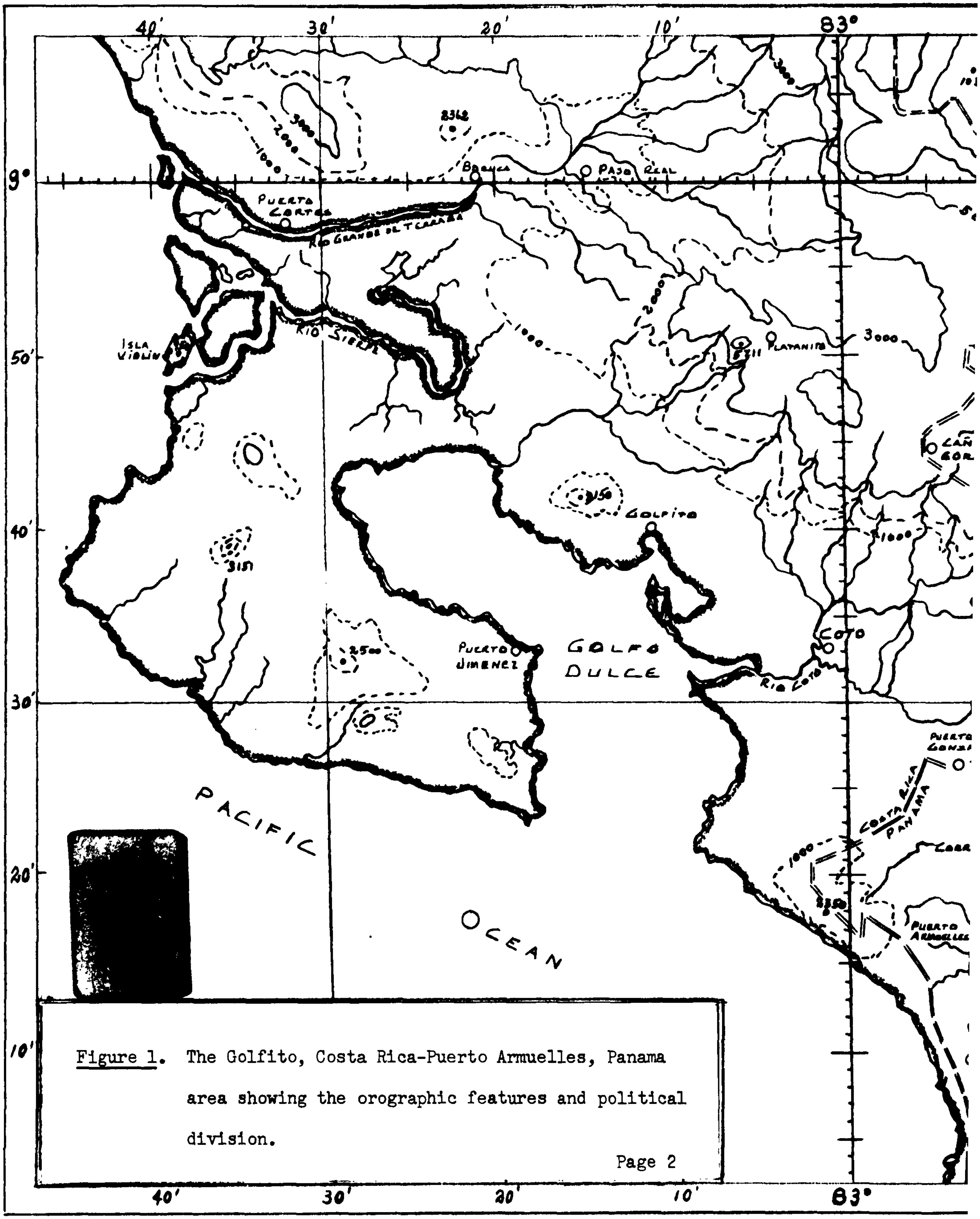
The monthly and annual rainfall data for El Salvador, Panama, Honduras, and British Honduras have been entered on punch cards. Certain programs have been run on the IBM 709 computer. These computations will be described later in this report. (Statistical analysis section)

Another requirement was for maps of the areas, this being especially true for the plantation areas where daily rainfall data were to be utilized for areal distribution. Maps on the scale of 1:500000 and on the scale of 1:250000 have been prepared. Stations have been located. Other maps of the same scale have been prepared showing the orographic features.

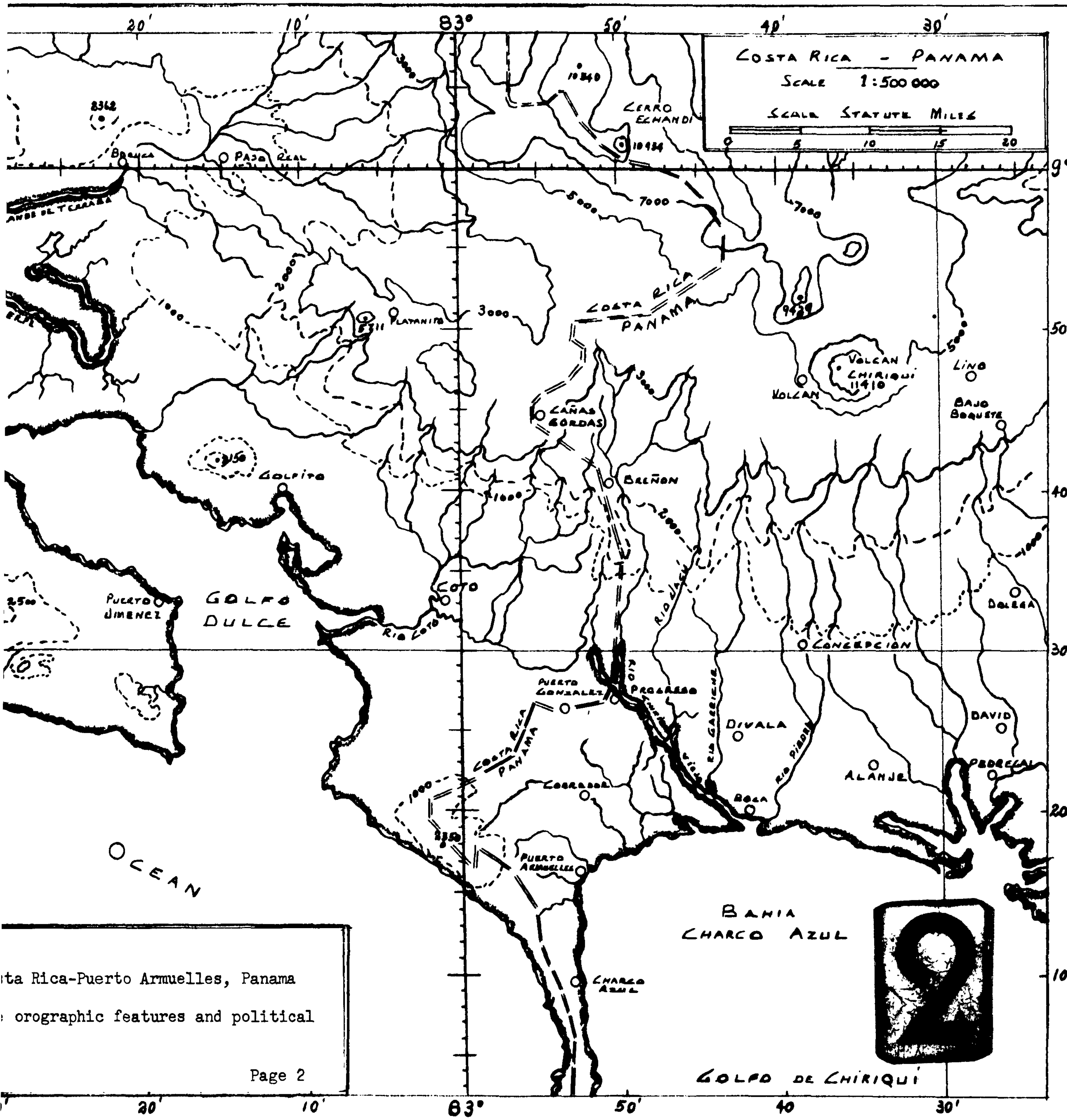
These maps are shown as Figures 1 thru 4.

Figure 1. The Golfito, Costa Rica-Puerto Armuelles, Panama area showing the orographic features and political division.

Figure 2. The Golfito, Costa Rica-Puerto Armuelles, Panama area showing the location of rain gages. The dots are United Fruit Plantations. The open circles represent cities and towns of the area.



<u>Figure 1.</u> The Golfito, Costa Rica-Puerto Armuelles, Panama area showing the orographic features and political division.



ıta Rica-Puerto Armuelles, Panama

: orographic features and political

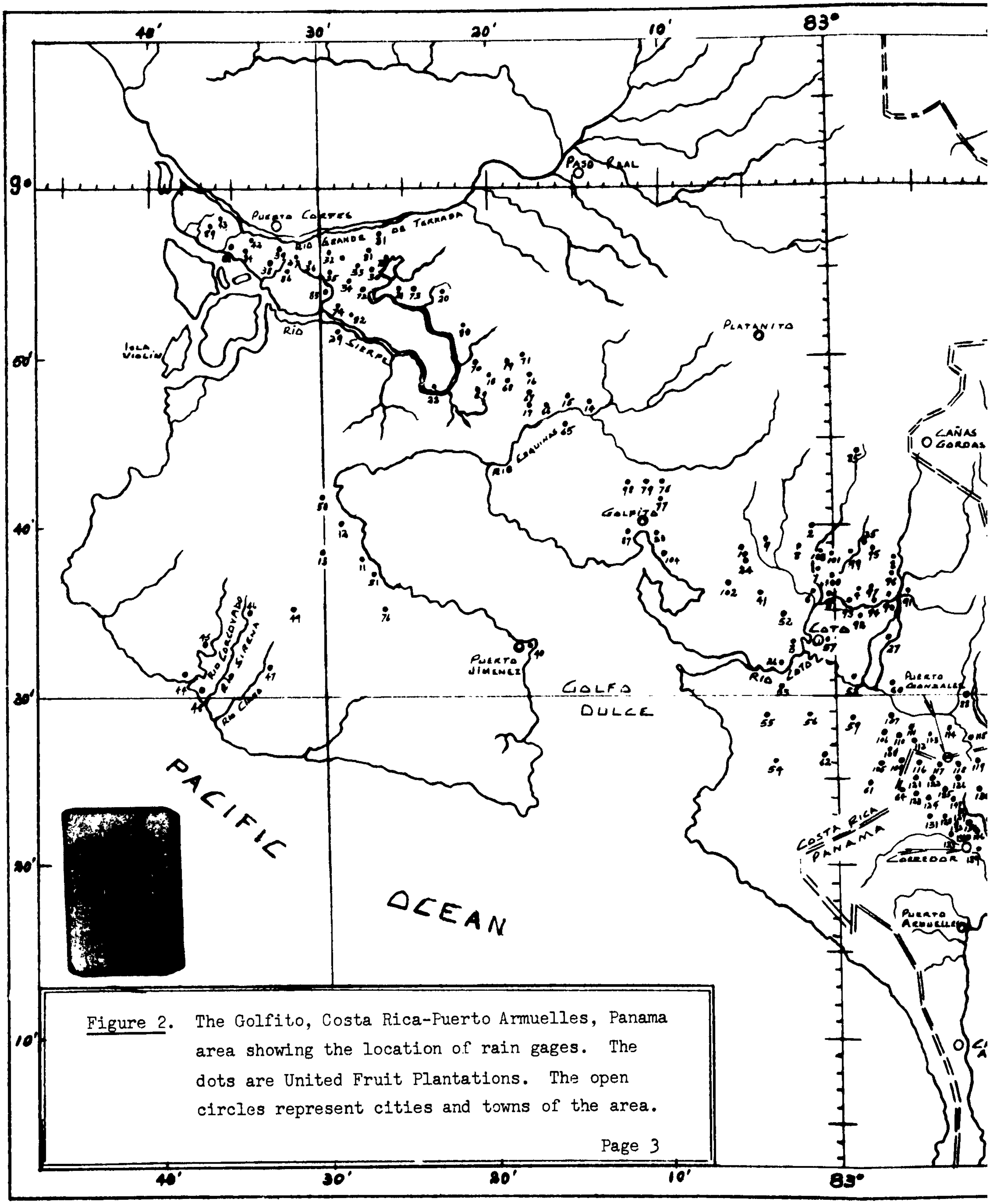
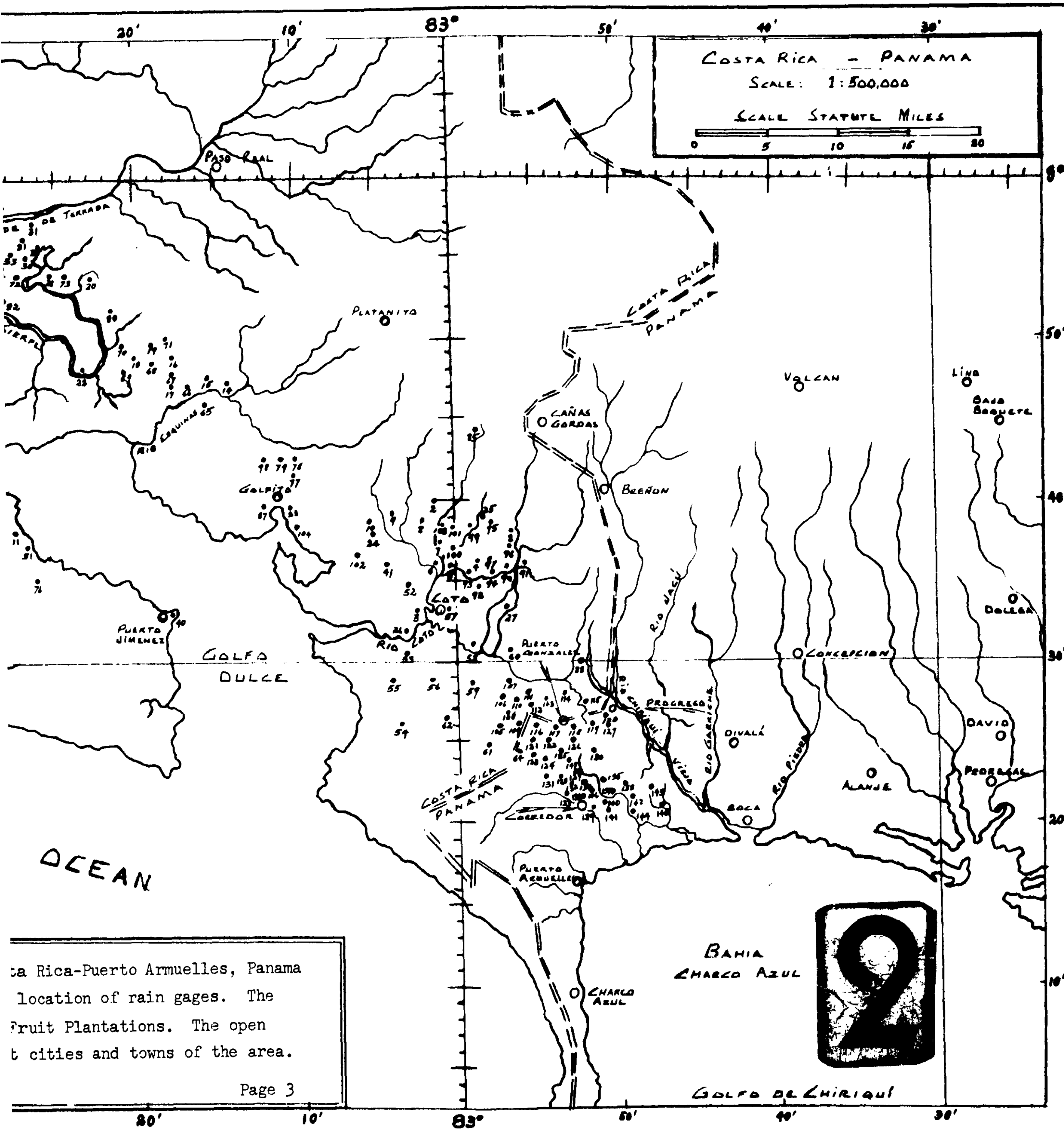


Figure 2. The Golfito, Costa Rica-Puerto Armuelles, Panama area showing the location of rain gages. The dots are United Fruit Plantations. The open circles represent cities and towns of the area.



ta Rica-Puerto Armuelles, Panama
location of rain gages. The
Fruit Plantations. The open
t cities and towns of the area.

Table I

Station Identifiers for Figure 2, the Golfito-Puerto Armuelles Area

No.	Location	No.	Location
1	Corredor	84	Finca 17
2	Caracol	85	Agua Buena
23	Golfito	86	Finca 15
25	Administracion	87	Arboleda Golfito
26	Pueblo Nuevo	90	Finca 42
27	Colorado	91	Finca 43
30	Finca 6	92	Finca 44
31	Palmar Sur	93	Finca 47
32	Finca 3	94	Finca 45
33	Finca 5	95	Finca 49
34	Finca 8	96	Finca 41
35	Finca 9	97	Finca 46
36	Finca 10	98	El Alto
37	Finca 11	99	Finca 48
38	Finca 16	100	Finca 50
41	Coto Junta	102	Independientes
50	Rincon	103	Finca 54
52	Quebrada Hedionda	104	Bolsa Golfito
53	Rio Conte Abajo	105	Naranjo
54	Rio Conte Arriba	106	Limon
55	Estero Sabalo	107	Caimito
56	Rio Incendio Boca	108	Cenizo
57	Quebrada Arena	109 (63)	Roble
58	Km.25 Line F. C. Coto	110	Caucho
59	Km.28 Line F. C. Coto	111	Mango
60	Coronillo	112	Bambito
61	Rio La Vaca	113	Puerto Gonzalez
62	Rio Incendio Arriba	114	Jobo
65	Finca Limon	115	Peral
66	Finca Alajuela	116	Sigua
67	Finca Heredia	117	Balsa
68	Finca San Jose	118	Almendro
69	Finca Cartago	119	Chuchupate
70	Finca Guanacaste	120	Quira
71	Finca Puntarenas	121	Corozo
72	Finca 7	122	Guayabo
73	Finca 18	123	Canaza
74	Finca 13	124	Bongo
75	Finca 1	125	Higueron & Bogamani
80	Finca Jalaca	126	Palmito
81	Finca 2	127	Maria
82	Finca 12	128	Zapatero
83	Finca 14	129	Blanco

TABLE I con't.

No.	Location
130	Caoba
131	Burica
132	Javillo
133	Majagua
134	Zapote
135	Jobito
136	Corredor
137	Jagua
138	Lechosa
139	Palo Blanco
140	Ceiba
141	Guayacan
142	Malagueto
143	Carana
144	Managa
145	Toroto
146	Nispero

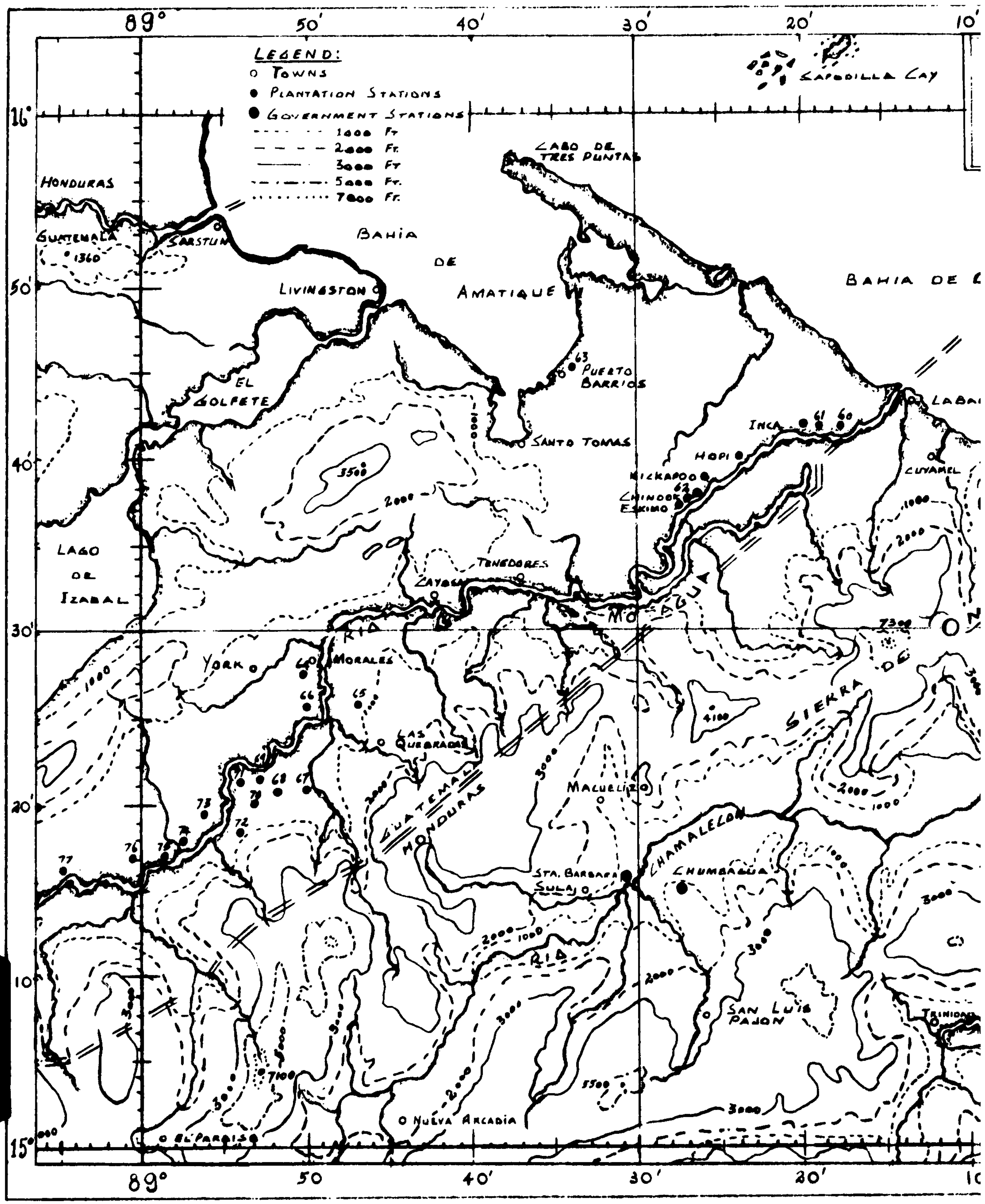
Figure 3. The Honduras-Guatemala area showing the orographic features and political divisions. The location of the rain gages, cities, and towns are identified. The plantations are owned and operated by the United Fruit Company.

Figure 4. The La Ceiba, Honduras area showing the orographic features and the location of the rain gages. The small solid circles are Standard Fruit plantations, the open circles are cities and towns while the large solid circles are stations reported by the Honduranian Weather Service.

Tables I and II identify the stations shown by numbers on Figures 2 and 3.

The La Ceiba area offers an excellent opportunity for investigations of rainfall variations with height. The ocean with inhabited islands offshore, a 8,000 foot mountain with a valley on the inland side are the existing features of terrain. The already established network of rain gages, the cooperative friendliness of both the Honduranian Weather Service, and the Standard Fruit Company make such a project feasible and desirable.

Because of the density of rain gages in some areas it is necessary to effect the analysis on a larger scale. A scale of 1:250000 has been found to be satisfactory.


LEGEND:
TOWNS
PLANTATION STATIONS
GOVERNMENT STATIONS
1000 FT.
2000 FT.
3000 FT.
5000 FT.
7000 FT.
89°
50'
40'
30'
20'
10'
16°
50'
40'
30'
20'
10'
15°
SAPODILLA CAY
CABO DE TRES PUNTAS
HONDURAS
GUATEMALA
1360
SARSTUN
BAHIA
DE
AMATIQUE
LIVINGSTON
BAHIA DE
EL GOLFETE
PUERTO BARRIOS
SANTO TOMAS
INCA
HOPI
KICKAPOO
CHINOOK
ESKIMO
CUYAMEL
3500
2000
1000
LAGO DE IZABAL
TENEDORES
CAYUGA
MOTAGUA
RIO
YORK
MORALES
LAS QUEBRADAS
GUATEMALA
HONDURAS
SIERRA
DE
7300
4100
MACUELIZO
CHAMALECON
STA. BARBARA
SULAJO
CHUMBAGUA
SAN LUIS PAJON
7100
5500
NUEVA ARCADIA
EL PARAISO

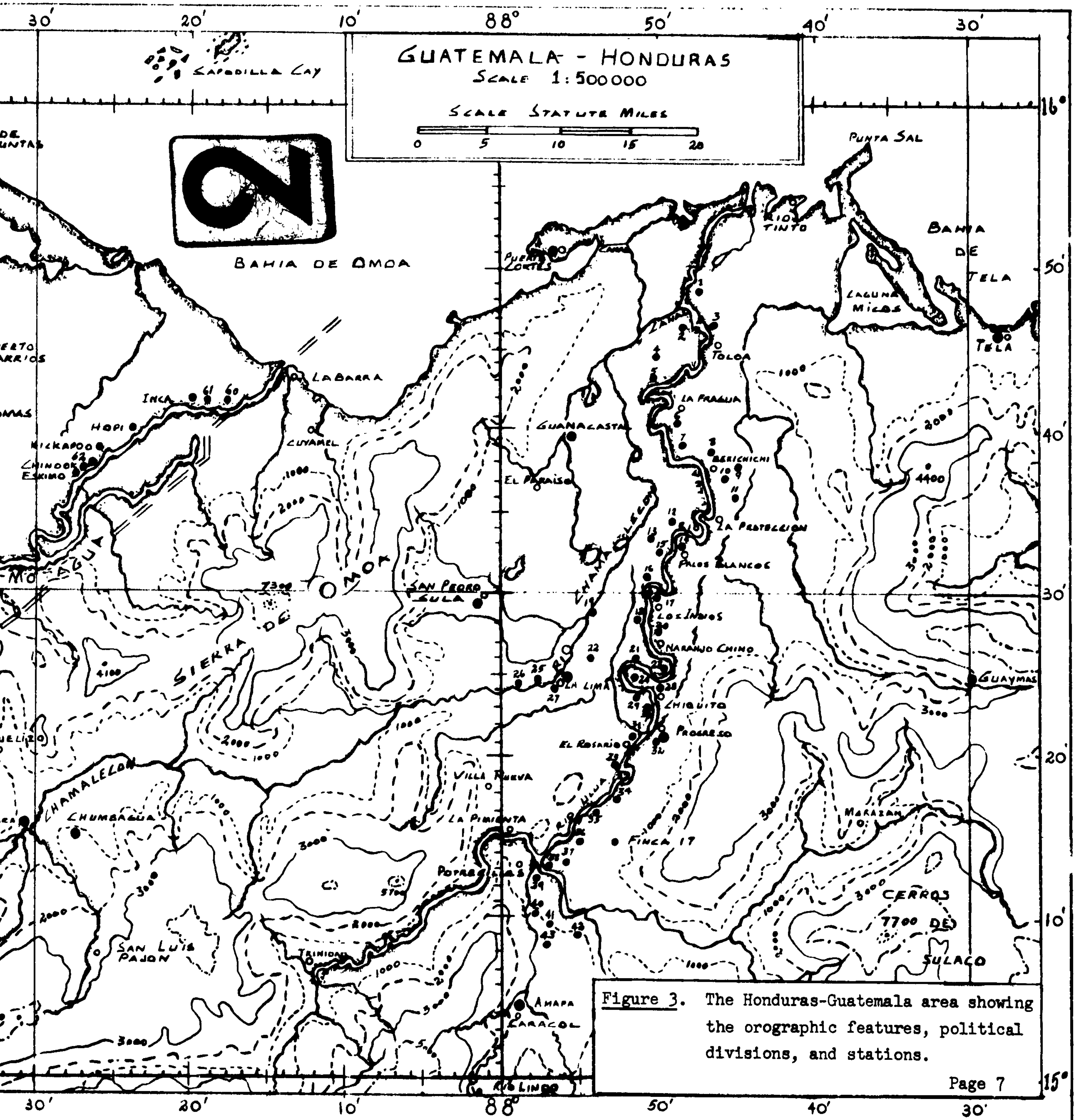
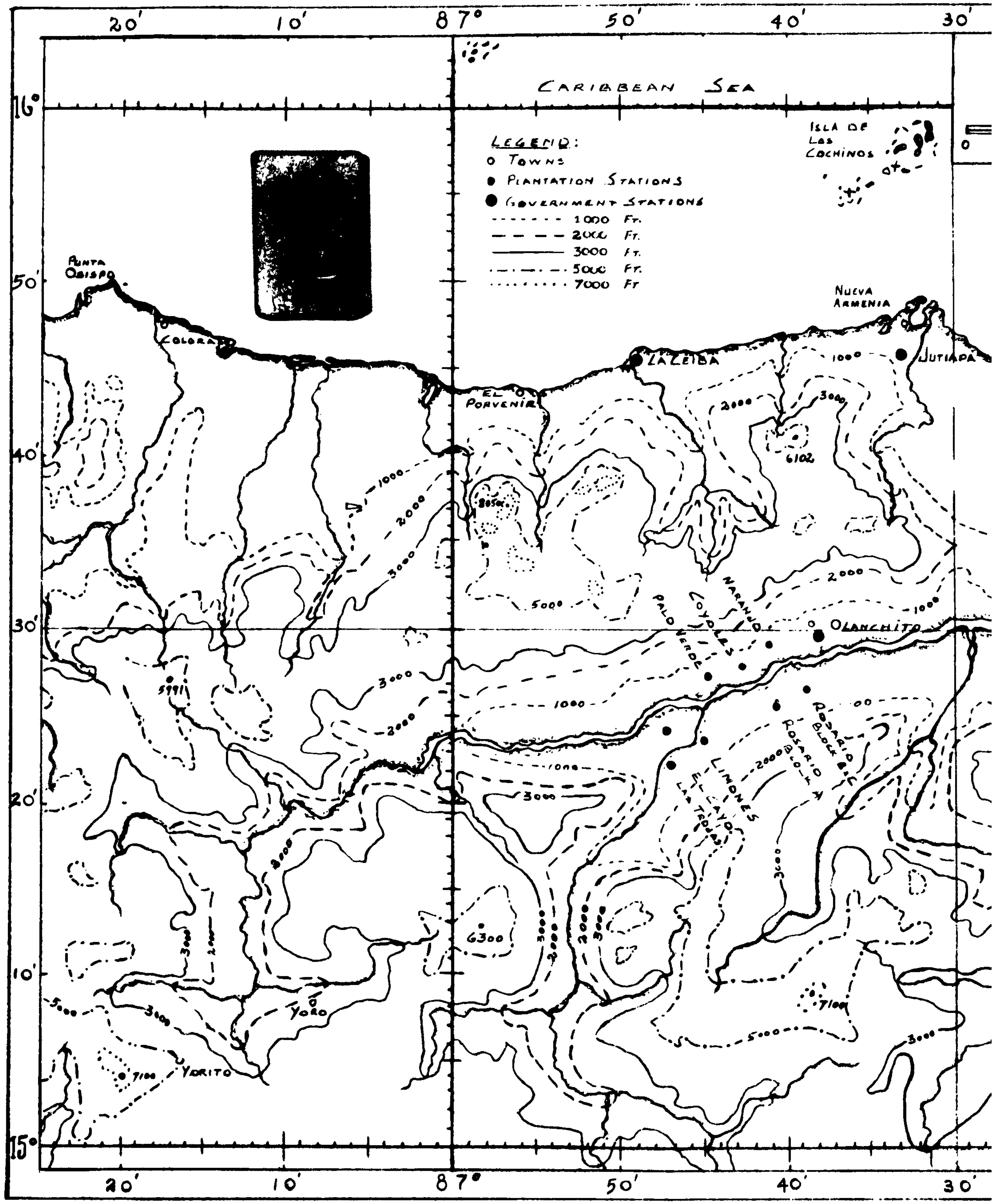


Figure 3. The Honduras-Guatemala area showing the orographic features, political divisions, and stations.

TABLE II

Station Identifiers for Figure 3, the Honduras-Guatemala Area

No.	Location	No.	Location
1	El Tigre	60	La Barra & El Paraiso
2	Nispero	61	Las Brisas
3	Melcher	62	Media Luna
4	Calan	63	Puerto Barrios
5	Guanacastal	64	Bananera
6	La Fragua	65	Cerritos
7	Birichichi	66	Oneida
8	Pavon	67	Onondega
9	Perdiz	68	Tikal - Sebol
10	Paujil	69	Panajachel
11	Guaymas	70	Zaculeu - Lanquin
12	Tibombo	71	Comanche
13	Lupo	72	Arapahoe
14	Monterrey	73	Patzum
15	Laurel	74	El Pilar
16	Los Limones	75	Yuma
17	Los Indios	76	Aztec
18	Indiana	77	Quirigua
19	Tacamiche		
20	Naranjo Chino		
21	Mopala		
22	San Juan		
23	Santa Rosa		
24	Cobb		
25	Zapote		
26	Guaruma		
27	La Lima		
28	Buena Vista		
29	Monte Vista		
30	Omohita		
31	Campin		
32	Progreso		
33	Travesia		
34	Finca 10		
35	Finca 11		
36	Finca 12		
37	Finca 18		
38	Finca 16		
39	Blanco		
40	Higuerito		
41	Barranco		
42	Llano		
43	Oliva		



20'
10'
87°
50'
40'
30'
16°
50'
40'
30'
20'
10'
15°
Caribbean Sea
Legend:
o Towns
• Plantation Stations
● Government Stations
1000 Ft.
2000 Ft.
3000 Ft.
5000 Ft.
7000 Ft.
Isla de Las Cochinos
Punta Obispo
Colorado
La Ceiba
El Porvenir
Nueva Armenia
Jutiapa
6102
8050
5991
Naranjo
Coyoles
Palo Verde
Olanchito
Rosario Block B & C
Rosario Block A
Limones
El Cayo
Las Tejas
6300
7100
Yoro
Yorito

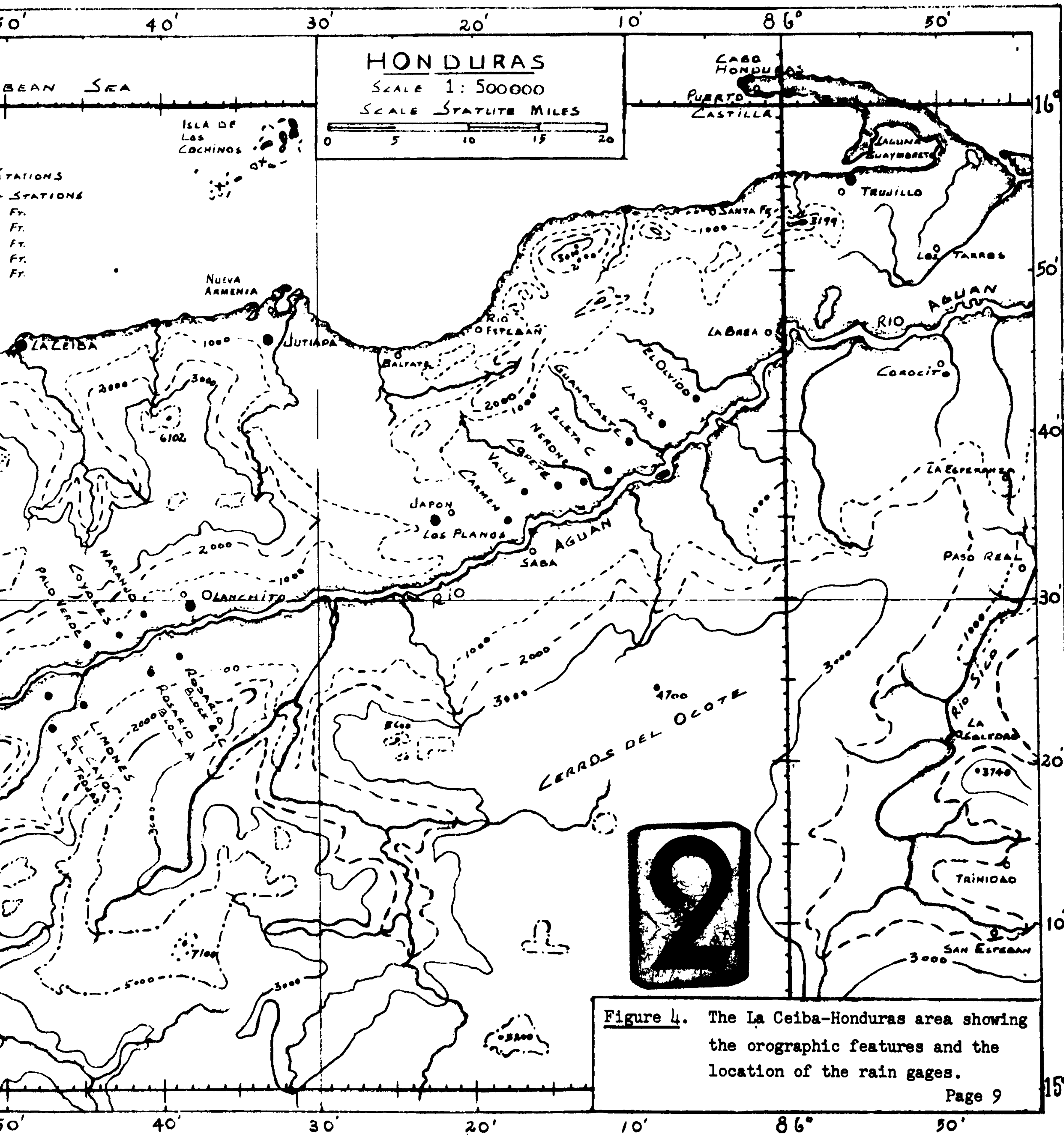


Figure 4. The La Ceiba-Honduras area showing the orographic features and the location of the rain gages.

B. Statistical Rainfall Analysis

In this preliminary areal investigation twenty stations in the western part of El Salvador have been selected. These stations comprise the only ones in that area for which there is a period of records of sufficient length to perform a statistical analysis.

The stations, with their identifying numbers, are as follows:

1	San Jeronimo	6	Santa Lucia
3	Metapan	7	Santa Ana
4	Texis Junction	8	Coatepeque
5	Chalchuapa	101	Ahuachaplan
102	Atiquizaya	304	San Andres
201	Sonsonate	308	Santa Tecla
202	Acajulta	309	Comasagua
301	Tepecoyo	501	La Toma
302	Ateos	502	La Cabana
303	Sitio del Nino	503	Apopa

The geographical locations of these stations are shown in Figure 5.

ANALYSIS

The number of monthly and yearly observations available varied between 10 and 47, so that, even with the larger samples, it is permissible only to use the Cornu and the third moment (skewness) tests for the study of the normality of the distribution. The fourth moment (kurtosis) can be used only when the sample size is of the order of 100 or more.

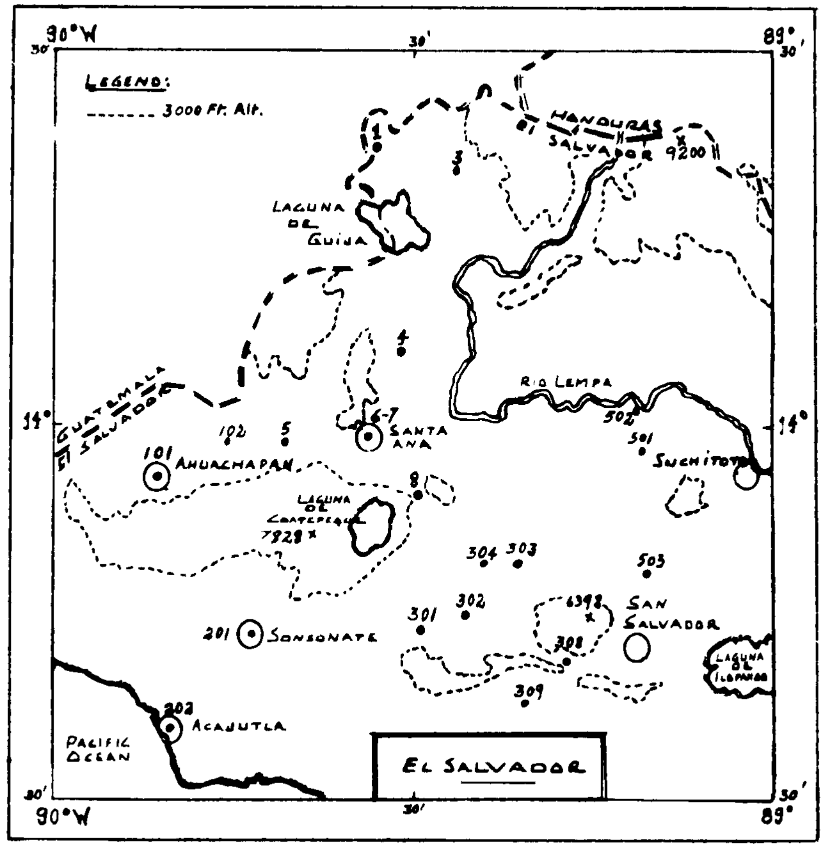


Figure 5.

Map of Western El Salvador Showing the

Locations of the Chosen Twenty Stations.

The tests themselves, outlined in the First Quarterly Report of this project, are not given here but will appear, in detail, in the Final Report.

Using the punched cards prepared for the stations, a program has been run at the Data Processing Center of the A. & M. College on the IBM 709 which supplies the parameters of first, second, and third moments of groups of data, plus similar information concerning their square roots.

Annual Totals

Using the actual observed annual totals for each year at each station, it was shown by the tests that 18 of the 20 had distributions not significantly different from normal.

Therefore, for these 18 stations, it is allowable to use tables of the normal distribution to calculate the probability of not receiving, or of exceeding a certain amount of precipitation in a year. It is also possible to calculate the limits between which a given percentage of the annual totals should fall and this has been completed in Table III for the 50%, 80%, 90%, and 99% ranges. The two non-normal stations have been included for comparison. The values in parentheses are the observed percentages. These are omitted for the 99% range as the number of observations is insufficient to give such a value any real meaning.

Monthly Totals

As was explained in the First Quarterly Report, it is necessary here to consider the square roots of all the monthly totals, testing

TABLE III

Summary of Results and Calculated Ranges for Annual Totals of Rainfall

At the Chosen Twenty Stations

Stn.	Res.	No. Yrs.	Mean	50% range	80% range	90% range	99% range	Observed Max.	Observed Min.
1	N	31	1464	1246-1682 (55)	1045-1883 (78)	928-2000 (87)	620-2308	2159	921
3	N	31	1562	1321-1803 (58)	1096-2028 (81)	966-2158 (87)	622-2502	2494	798
4	N	30	1758	1560-1956 (47)	1380-2136 (78)	1274-2242 (93)	997-2519	2444	1194
5	X	33	1951	1677-2225 (52)	1425-2477 (88)	1277-2625 (91)	891-3011	2669	1214
6	N	34	1990	1810-2170 (41)	1645-2335 (74)	1548-2432 (91)	1294-2686	2419	1496
7	N	47	1707	1444-1970 (53)	1202-2212 (81)	1060-2354 (87)	688-2726	2521	660
8	N	44	1774	1591-1957 (55)	1424-2124 (75)	1325-2223 (91)	1068-2480	2347	1241
101	N	33	1916	1707-2125 (43)	1516-2316 (82)	1403-2429 (94)	1109-2723	2706	1411
102	N	33	1787	1598-1976 (48)	1425-2149 (85)	1324-2250 (91)	1057-2517	2586	1255
201	N	46	1912	1656-2168 (52)	1421-2403 (76)	1283-2541 (85)	922-2902	2641	1206
202	N	47	1732	1520-1944 (49)	1326-2138 (70)	1212-2252 (94)	914-2550	2347	1243
301	N	10	2004	1844-2164 (50)	1694-2314 (70)	1607-2401 (100)	1380-2628	2333	1672
302	N	23	1548	1368-1728 (48)	1204-1892 (74)	1108-1988 (96)	856-2240	2104	1133
303	N	25	1570	1402-1738 (44)	1248-1892 (72)	1157-1983 (96)	920-2220	2021	1162
304	N	15	1711	1575-1847 (60)	1449-1973 (73)	1357-2047 (87)	1183-2239	2075	1407
308	X	20	1880	1695-2065 (55)	1525-2235 (95)	1428-2332 (95)	1165-2595	2697	1527
309	N	11	2054	1812-2296 (55)	1589-2519 (82)	1458-2650 (91)	1117-2991	2388	1282
501	N	31	1927	1703-2151 (48)	1497-2357 (77)	1376-2478 (87)	1061-2793	2659	1302
502	N	18	1758	1624-1892 (56)	1501-2015 (72)	1427-2089 (89)	1237-2279	2122	1415
503	N	33	1958	1774-2152 (49)	1605-2311 (85)	1505-2411 (91)	1246-2670	2742	1506

these for normality. For the twenty stations this gave a total of 240 months and of these 161 were identified as being not significantly different from normal.

It is clear, however, that months with a small average rainfall will generally have a large number of zeroes, thereby invalidating an assumption of normality due to a truncation effect.

Using a criterion deduced from this present analysis, it has been found that, if for the month the coefficient of variation ($\frac{100\ \sigma}{\bar{x}}$) for the square roots is less than 105, the month is likely to have a distribution not significantly different from the square root normal pattern. The actual analysis showed that of the 162 station-months with a coefficient of variation less than 105 there were 147 (91%) satisfying the normality tests. This percentage of success is identical with the 91% level found in the analysis of monthly totals of East African stations.*

The criterion concerning the coefficient of variation is roughly equivalent to stating that the monthly mean should exceed about 10mm or 0.4 inch.

Of the 24 months with a coefficient of variation of 200 or more, none was normally distributed.

The threshold level of 105 was obtained empirically being the value at which the percentage success value, which was always large, began to decrease. The position of the threshold may alter when the

*J. F. Griffiths. Proc. W.M.O./Munitalp Symposium on Tropical Meteorology, Nairobi, 1959.

full analysis is completed but is not expected to be outside the 100-110 range.

Table IV gives details of the results of comparing the coefficient of variation with the distribution, the normal months being underlined.

It also became clear from the analysis that as the monthly average rainfall increased the coefficient of variability, V, decreased and a graph of this is given in Figure 6. The graph shows that while it is possible to make a rough estimate of the coefficient of variation when $\bar{x}$ is known, the deduced value may be in appreciable percentage error for any one station-month.

In Table V are given the values of the 50%, 80%, 90%, and 99% ranges, together with the observed percentage for two months for all stations.

TABLE IV

Coefficient of Variation for Each Station and Month

Stn.	Month of Year 1	2	3	4	5	6	7	8	9	10	11	12
1	210	229	103*	54	34	18	23	21	17	24	110	216
3	557	177	90	59	25	21	27	19	16	27	108	202
4	277	203	112	58	25	15	17	19	19	25	85	179
5	185	259	142	86	29	19	18	18	13	31	100	177
6	195	229	134	52	18	14	14	14	12	23	91	163
7	226	338	174	69	24	17	20	20	17	29	91	165
8	299	404	186	62	24	16	17	15	13	23	84	184
101	229	249	176	75	25	15	17	14	16	30	97	149
102	217	210	137	75	24	16	17	13	14	30	93	167
201	237	257	148	57	24	17	19	17	21	26	87	169
202	228	342	160	72	30	19	21	19	22	30	113	172
301	175	111	148	71	20	17	14	15	20	23	87	170
302	242	283	126	50	24	19	17	13	18	28	86	191
303	195	217	153	49	19	16	17	14	14	21	68	176
304	139	139	95	50	24	15	12	11	13	17	69	141
308	101	181	92	63	20	18	17	13	21	23	56	130
309	133	151	133	39	27	22	15	15	16	21	79	156
501	166	174	139	56	22	15	16	14	10	20	87	181
502	122	135	141	42	18	16	18	11	16	20	69	142
503	173	210	154	58	22	19	12	13	13	19	75	144

*Underlined values connote normality.

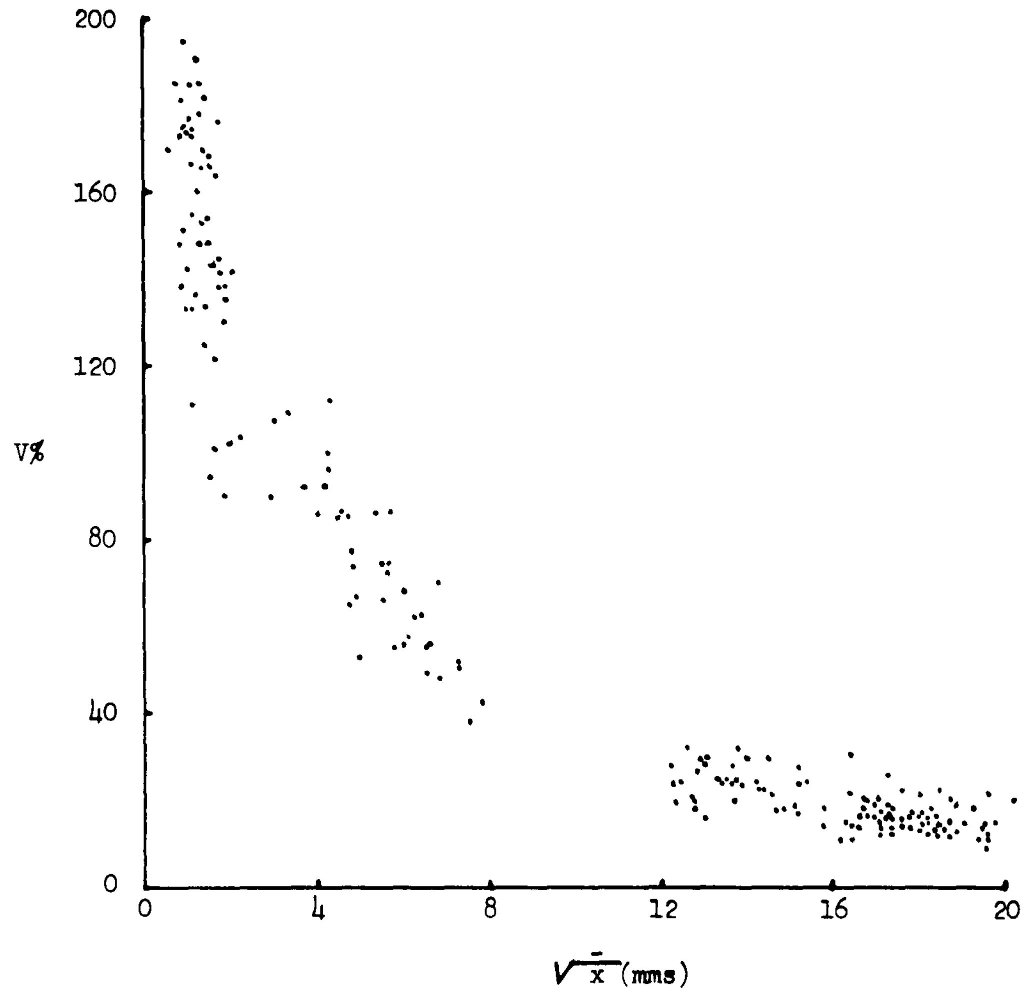


Figure 6.

Comparison Between the Coefficient of Variation (%) and the Mean of the Square Roots of the Monthly Rainfall (mm).

TABLE Va

Summary of Results and Calculated Ranges for August Totals of Rainfall

At the Chosen Twenty Stations

Stn.	Res.	No. Yrs.	Mean	50% range	80% range	90% range	99% range	Observed Max.	Observed Min.
1	N	31	213	156-278 (52)	112-346 (81)	90-388 (97)	44-511	597	104
3	N	31	228	174-289 (48)	130-353 (71)	106-396 (90)	58-511	412	102
4	N	30	282	216-357 (50)	164-433 (90)	137-480 (90)	77-615	569	105
5	N	33	324	250-408 (42)	190-493 (85)	159-548 (94)	90-702	782	168
6	N	34	320	262-384 (50)	213-449 (85)	185-493 (88)	125-605	602	163
7	N	47	289	216-372 (49)	156-462 (81)	128-515 (89)	64-676	632	82
8	N	44	299	243-361 (48)	196-424 (82)	169-467 (91)	112-576	513	122
101	N	33	331	272-396 (45)	225-458 (88)	199-497 (94)	137-610	571	150
102	N	33	292	243-346 (42)	204-396 (76)	182-428 (91)	130-520	483	174
201	N	46	289	228-357 (46)	177-430 (85)	149-475 (91)	90-600	490	102
202	N	47	250	190-317 (40)	144-384 (83)	119-428 (91)	66-552	496	88
301	N	11	320	260-385 (36)	213-449 (91)	185-493 (91)	125-605	448	163
302	N	23	272	228-320 (61)	188-372 (78)	166-404 (87)	117-493	419	132
303	-	25	250	204-299 (68)	169-346 (84)	149-376 (88)	102-462	400	87
304	N	15	269	234-306 (60)	202-346 (73)	185-369 (87)	144-433	382	165
308	N	20	306	256-361 (65)	210-416 (85)	188-454 (85)	135-548	567	181
309	N	11	335	269-408 (45)	216-480 (82)	188-524 (100)	123-650	503	190
501	N	31	324	266-388 (48)	219-449 (81)	172-488 (94)	132-600	472	160
502	N	18	262	225-299 (56)	193-342 (83)	174-369 (94)	135-433	430	190
503	N	33	339	286-396 (36)	240-454 (85)	213-493 (94)	156-590	587	172

TABLE Vb

Summary of Results and Calculated Ranges for October Totals of Rainfall

At the Chosen Twenty Stations

Stn.	Res.	No. Yrs.	Mean	50% range	80% range	90% range	99% range	Observed Max.	Observed Min.
1	N	31	154	108-207 (52)	65-262 (81)	56-299 (90)	22-104	376	33
3	N	31	169	114-234 (45)	72-306 (77)	53-350 (90)	16-484	371	42
4	N	30	180	125-243 (47)	85-310 (80)	64-353 (93)	24-480	432	41
5	N	33	188	117-276 (48)	67-369 (82)	43-433 (94)	7-615	476	13
6	N	34	199	142-266 (47)	98-335 (82)	75-380 (94)	31-511	388	36
7	N	47	169	110-240 (55)	65-320 (85)	46-369 (89)	10-520	552	23
8	N	44	188	135-250 (43)	96-310 (84)	74-353 (95)	32-471	502	62
101	N	33	210	135-303 (52)	81-400 (82)	55-467 (88)	12-655	665	41
102	N	33	196	125-282 (52)	74-376 (85)	49-441 (91)	10-615	528	11
201	N	46	296	202-408 (50)	130-529 (78)	96-605 (91)	31-820	743	97
202	-	47	266	169-384 (60)	100-511 (79)	69-590 (85)	14-835	731	28
301	N	11	240	174-319 (27)	121-400 (91)	96-449 (100)	42-600	382	103
302	N	23	149	98-210 (43)	61-276 (83)	44-317 (91)	12-441	336	20
303	N	25	159	117-207 (44)	83-260 (80)	67-289 (96)	31-384	280	48
304	N	15	169	132-210 (40)	104-250 (87)	88-276 (93)	53-350	264	74
308	-	20	237	172-313 (20)	119-396 (95)	94-445 (95)	41-595	382	80
309	N	11	324	240-420 (36)	172-524 (82)	139-586 (91)	67-773	482	118
501	N	31	188	139-243 (48)	102-299 (77)	83-335 (90)	42-437	343	61
502	N	18	161	122-207 (55)	90-253 (78)	74-282 (94)	38-369	351	77
503	N	33	216	164-276 (39)	123-335 (91)	105-369 (94)	56-480	335	66

Special Considerations

(a) Estimation of number of zeroes

There is a difficulty arising from the use of the simple square root normal distribution when the coefficient of variation, V, is high, above about 50, this is the problem of negative values. For example, if V is 100, then a deviation of over 1.0 σ will give a negative calculated rainfall, and such a deviation has about a one in six chance of occurrence. Although this is a theoretical argument against the method, it need not cause trouble in practice.

A logical approach to the calculation of the number of zeroes appears to be as follows:

using whole millimeters, a reading of up to 0.49 will be counted as 0; this has a square root of 0.7, so that any value of 0.7 or less will be the same as 0 rainfall.

Thus, if $\bar{x} = 2.2$ and $\sigma_x = 2.0$, a deviation of more than $-0.75\ \sigma_x$ will give zero untransformed values since:

$$(2.2 - 0.7) = 2.0 \times (0.75)$$

Then, the number of zeroes becomes 22.7% of the number of observations.

(b) Likely errors

It is sometimes possible to identify likely errors in the original data by means of deduction from the analysis, for example:

> Station 1, Month 5 has a rainfall in 1934 such as is likely only once in 200 years, namely 574 mm. In month 6 in the same

year the rainfall is again given as 574 mm, thus suggesting a clerical error.

(c) Rapid calculation of mean square root

It appears that as the mean monthly value increases the square root of this number more closely approaches the mean of the square root values. The graph of this relationship, using most of the 240 months, is shown in Figure 7 and it is seen that for values of the mean above about 100 mm the relationship can be used to estimate the new square root mean with sufficient accuracy.

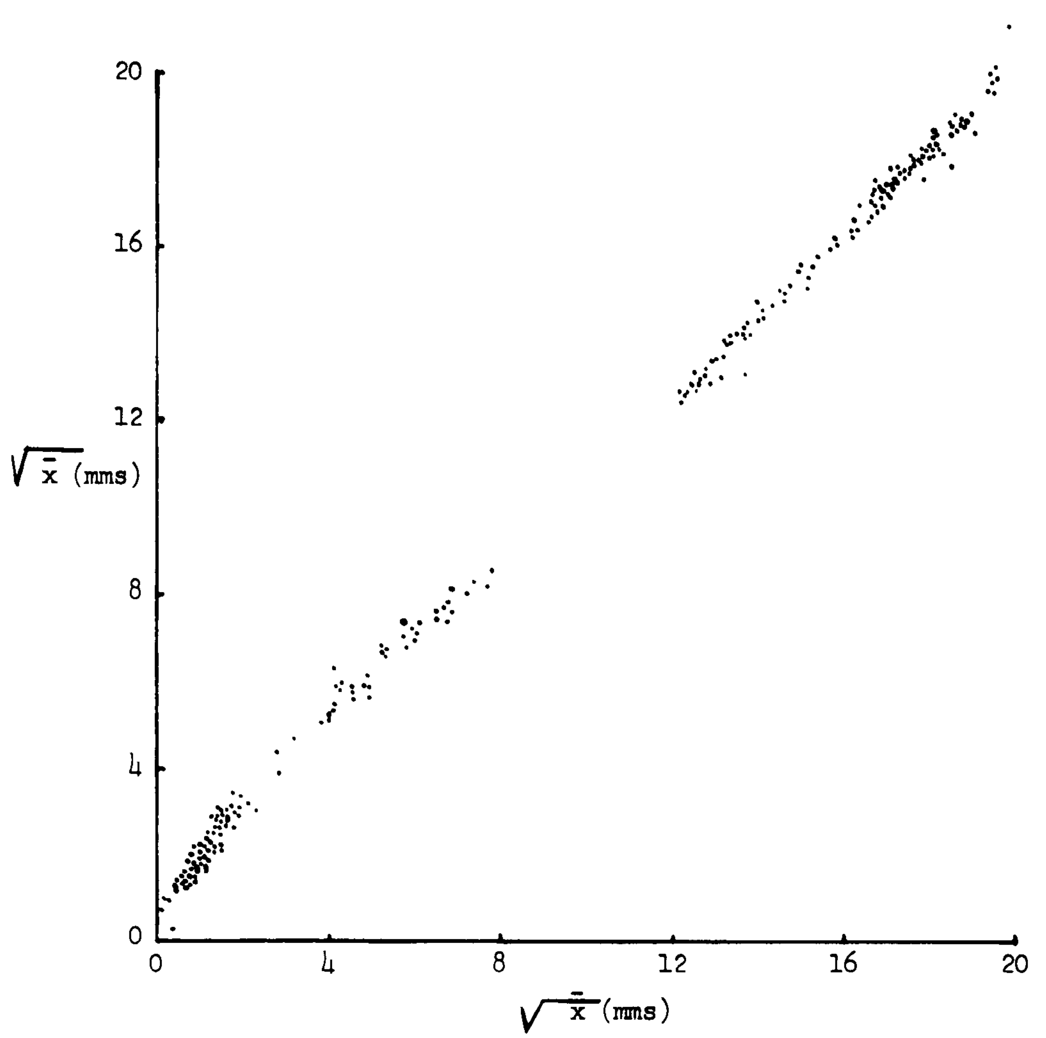


Figure 7.

Comparison Between the Square Root of the Mean Monthly Rainfall and the Mean of the Square Roots of the Monthly Values.

C. Meso-Scale Rainfall Analysis

Using a network of closely spaced rain gages, an attempt was made to determine the meso-scale pattern of rainfall and the meso-scale systems which produced the rainfall.

In any analysis, the data accuracy is suspect. In this region the rainfall is measured once a day at approximately 7 A.M. The reports are phoned into a central office where they are compiled daily. In such a system all the inherent errors of the rain gage are present. Also the observer is not a professional weather man. Many of the gages are neither properly exposed nor maintained. The data have been compiled and some of them copied by hand more than once. There are certain to be errors in these data. However, it is believed to be usable, if the analyst does not concern himself with the hundredth figure, or even the tenths figure. If he is willing to accept the viewpoint that a report of 4.36 inches represents considerably more rainfall than a report of 0.58 inches, an analysis can be prepared. In general the differences from station to station are such as to indicate that one station had a heavy rainfall while another had little or none.

Another problem is that there is no indication of the time of day when the rain fell. Also the data do not indicate the number of times it rained during the 24 hour period to amass the total. The duration of each rainfall is unknown.

In an effort to determine the meso-scale systems some assumption needs to be made as a starting point. After scanning some of the maps with daily rainfall plotted, it came apparent that a cluster of stations had an inch or more of rain while many others had only small fractions of an inch. With a feeling that only the stronger meso-systems could be identified, the assumption was made, and used, that the area enclosed by the one inch isohyet represented one or more meso-systems. Although it is known that one cumulus cell in the tropics may precipitate several inches, say eight, upon one rain gage, the general concept used in analyzing these maps is that several inches of rainfall is caused by more than one meso-system. The small amounts are assumed to be from weak systems or small individual cells. These assumptions were used in the analysis presented in this report. As the investigation continues, better concepts may evolve. It may be that the rainy season will need a different criterion from the dry season. Selected cases will be discussed.

Case 1. On June 14, 1960, there were two well defined rain areas within the data coverage. These areas are shown in Figure 8. Each of these represents a meso-scale system. System A as enclosed by the one inch isohyet is about 5 miles wide and 8 miles long, with a total area of about 36 square miles. The individual system is estimated to be almost circular in shape and of 5 miles diameter. It was moving either north or south to give the oblong pattern. Small amounts of rain fell outside of the one inch isohyet, about 6 miles to the north and 3 miles to the south. East-west did not have enough data to define the edge of the rainfall area.

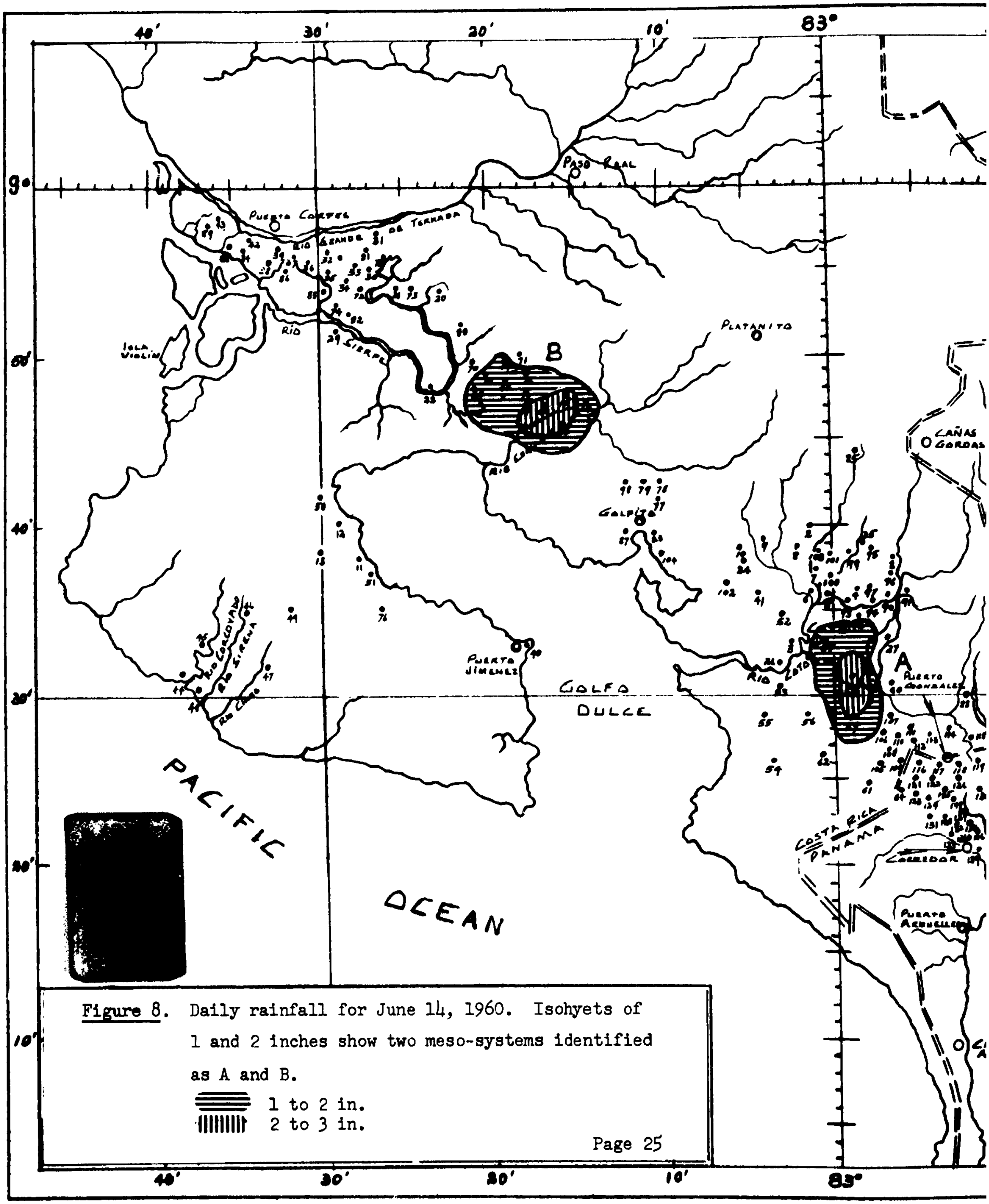
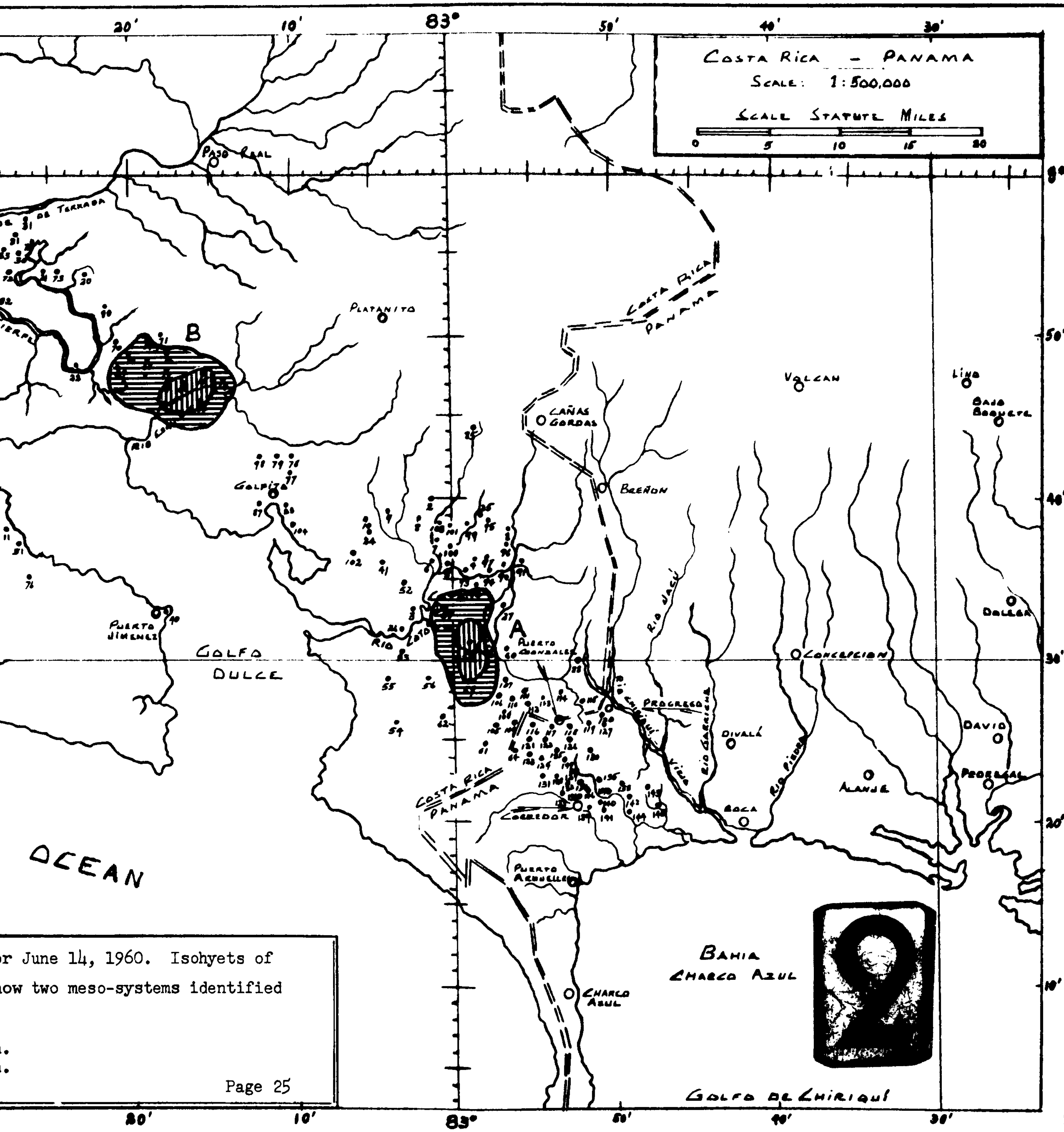


Figure 8. Daily rainfall for June 14, 1960. Isohyets of 1 and 2 inches show two meso-systems identified as A and B.

1 to 2 in.
2 to 3 in.



r June 14, 1960. Isohyets of
now two meso-systems identified

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Meso-system B is not as uniquely defined by the data, but it was operating as a separate system from system A. System B is larger in area and caused more rainfall.

Case 2. On July 14, 1956, there were several well-separated rainfall areas. The meso-systems were small, being of the order of 4 mile diameter. Also only two stations reported as much as two inches of rain. The analysis is shown in Figure 9.

Meso-system A and B are weak and may be the combined effect of weak systems rather than the individual systems shown. There was scattered rainfall, mostly less than three-tenths inch all around these systems.

Meso-system C was stronger, but the data do not define it. This system, along with A and B, does not appear to move, nor be a strong system.

Meso-system D unfortunately is not well defined by the data. This rainfall area is surely the combined effect of two or maybe three systems. The northeast edge of these systems is well defined with eight stations reporting no rain between system D and system E.

Systems E and F are not sufficiently in the data to give any information.

Case 3. On July 5, 1956, meso-systems were active and analyzed in Figure 10. Systems A and E were on the edge of the data. System D has the same characteristics as discussed in cases 1 and 2. It seems to have little movement.

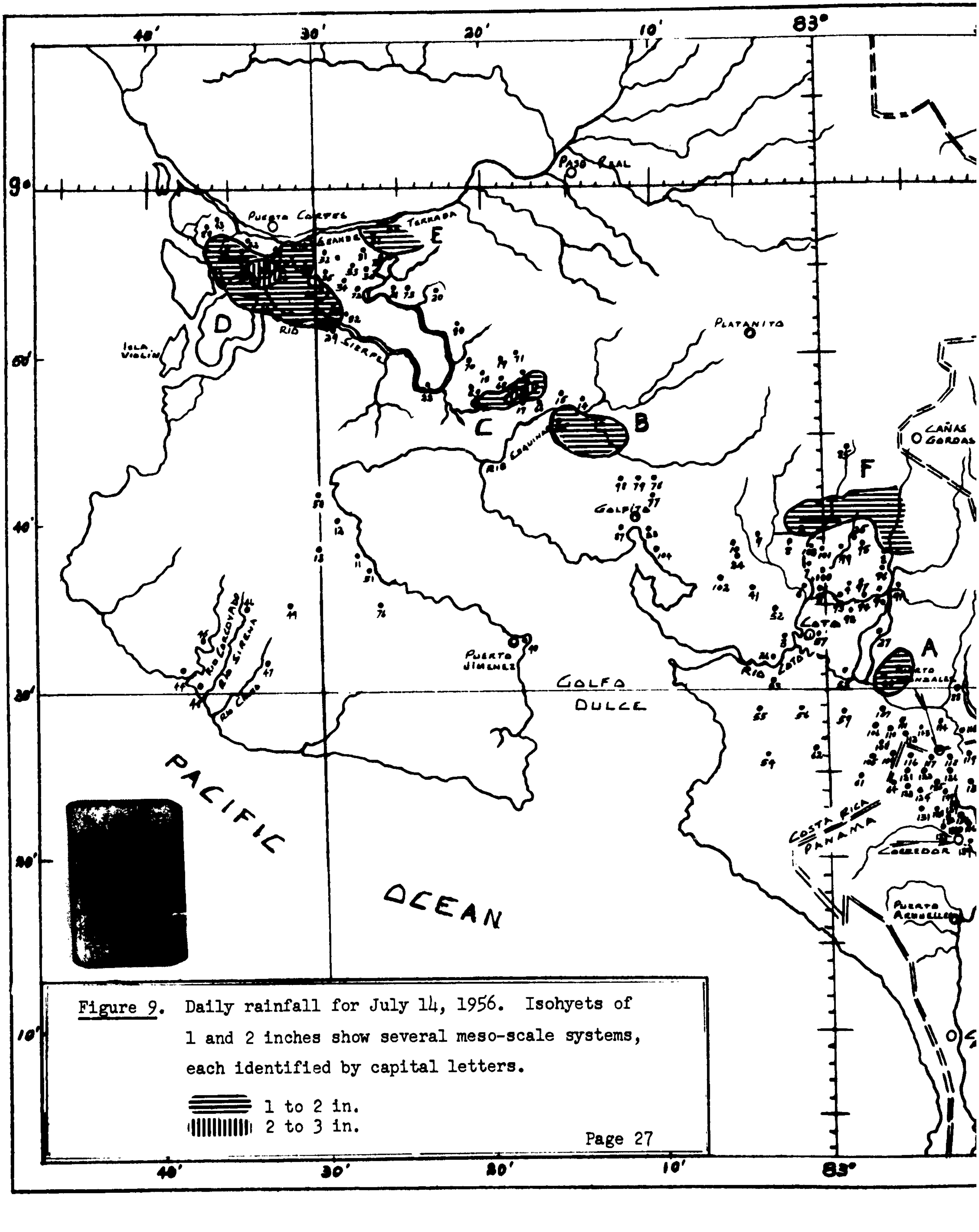
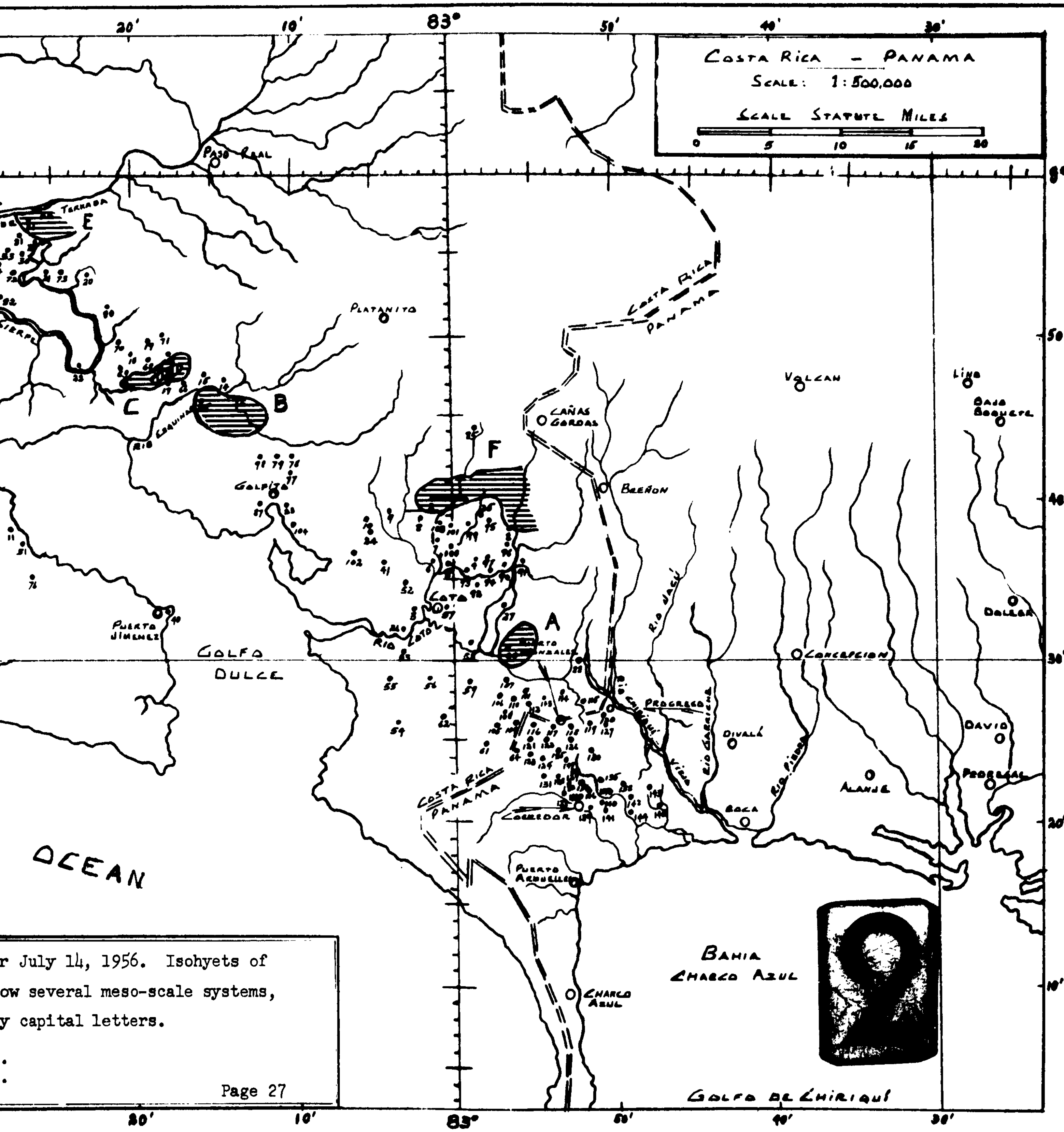


Figure 9. Daily rainfall for July 14, 1956. Isohyets of 1 and 2 inches show several meso-scale systems, each identified by capital letters.

1 to 2 in.
2 to 3 in.



r July 14, 1956. Isohyets of
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Meso-systems B and C are the most interesting of this day. This is a case of two systems in the same area. They may have occurred simultaneously, but the best estimate is that they were separated in time. This rain area shows two separate maximum rainfall centers. The pattern of the one inch isohyet is the combination of the two meso-systems.

Crow and Cobb,* using radar and cloud photographs have identified an individual cell size of about 1½ miles in diameter. This being the case, then these meso-systems must be a cluster of cells. Crow and Cobb indicated that the cells were found in clusters. They identified the life of a cell to be 20 to 25 minutes. Using this information and the data presented, the following is deducted. The meso-scale system consists of a cluster of cells. This system causes heavy rainfall in restricted areas. Scattered light rainfall over adjacent areas is caused by cells, many of which would represent the break-up of the system.

The same type of analysis has been attempted using monthly totals. At this time no results are available, but some of the patterns are interesting. There is a large variance of rainfall between stations.

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*Loren W. Crow and Glen Cobb, "Life Cycles of Tropical Cumulus in Southwest Panama." Final Report NSF Contract C-184, Sept., 1962.

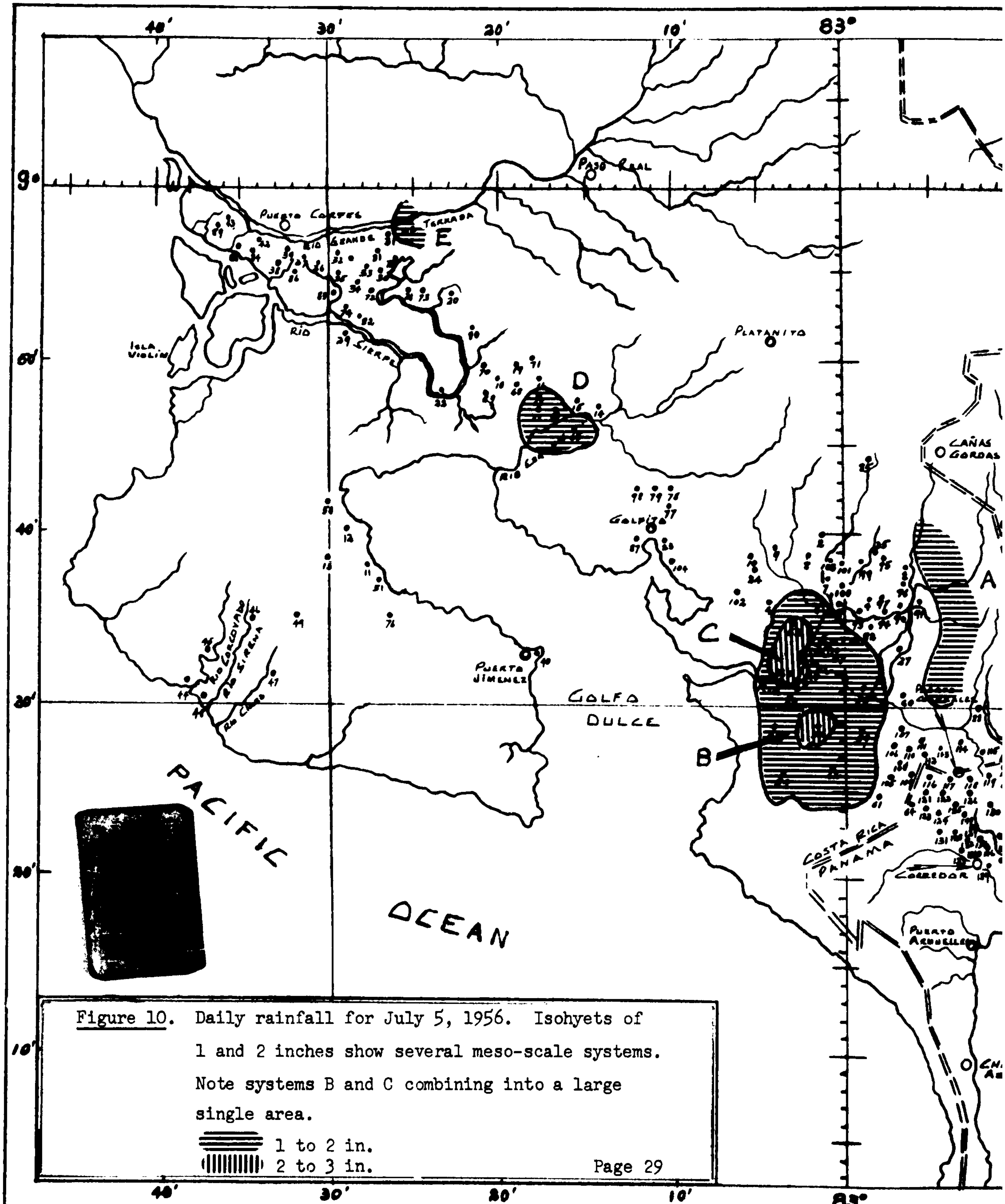
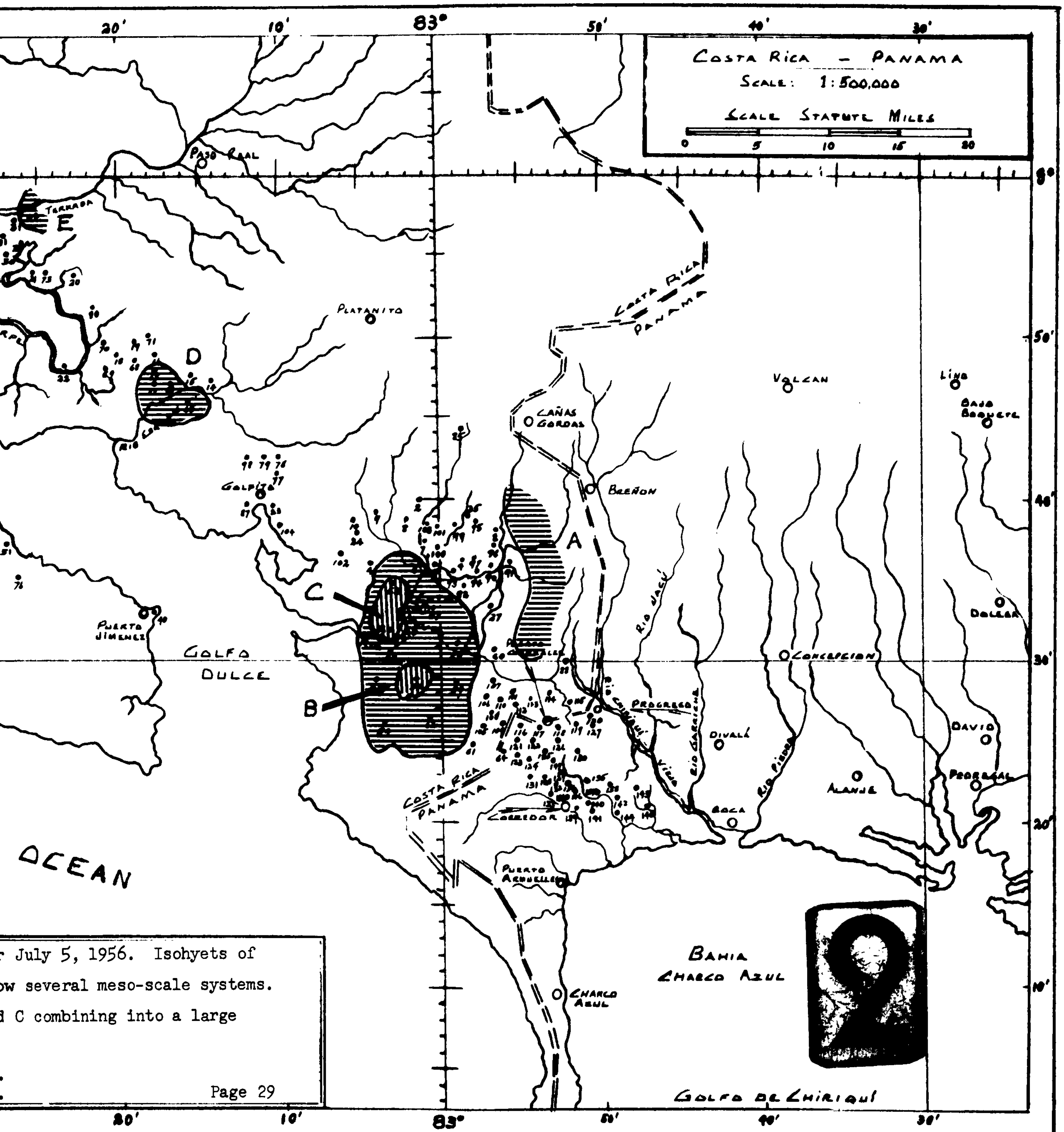


Figure 10. Daily rainfall for July 5, 1956. Isohyets of 1 and 2 inches show several meso-scale systems. Note systems B and C combining into a large single area.

1 to 2 in.

2 to 3 in.



r July 5, 1956. Isohyets of
ow several meso-scale systems.
d C combining into a large
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CONCLUSIONS

The annual and monthly rainfall values for stations in western El Salvador were shown to be tractable to the same pattern of statistical analysis as had been proved satisfactory in the African Tropics. The degree of success was most hopeful, and it augurs well for the future analysis.

The analysis of the daily rainfall maps was interesting. The fact that the areal variations of rainfall could be shown so well was encouraging. The one inch isohyet was used to delineate the area effected by a meso-scale system. To date this procedure has been successful.

PROGRAM FOR NEXT PERIOD

During the next period, it is planned:

a. To expand the areal coverage of the statistical analysis, especially into Honduras and British Honduras.

b. To continue the analysis of daily rainfall data in the Golfito, Puerto Armuelles area. Also the monthly rainfall areal distribution will be investigated.

c. To start the analysis of daily rainfall data along the Honduras -Guatemala area and the La Ceiba, Honduras area. The comparison of these almost parallel river valleys should be interesting.

PERSONNEL

The following personnel were engaged during this quarter:

Name	Date Started	Date Ended	Fraction	Total Hours
Matthew Bastardi Student Assistant	Nov. 1	Dec. 31	Hourly rate	71½
Daniel J. Gramatges Tech. Assistant	Oct. 1	Dec. 31	Full	520
John F. Griffiths Asst. Professor	Sept.1 Dec. 1	Nov. 30 Dec. 31	½ ¼	260 40
Walter K. Henry Asst. Professor	Sept.1	Dec.31	¼	170
Allen B. Lee Student Assistant	Dec. 1	Dec. 31	Hourly rate	12½
Dale F. Leipper* Department Head	Sept.1	Dec. 31		
Stephen Kent Rinard Student Assistant	Dec. 1	Dec. 31	Hourly rate	10½
David R. Smith Student Assistant	Nov. 1	Dec. 31	Hourly rate	69
Judith E. Stradinger Sec - Computer	Sept. 1	Dec. 31	Full	680

*Dr. Dale F. Leipper is Head of the Department of Oceanography and Meteorology, and Project Supervisor, at no cost to the project. He gives general guidelines, but the administration and operation of the project is accomplished by Mr. Henry in addition to his research functions.

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RESEARCH ON TROPICAL RAINFALL PATTERNS AND ASSOCIATED MESO-SCALE SYSTEMS

John F. Griffiths & Walter K. Henry

Report No. 2, 2nd Quarterly Report - 1 Sept. 1962 to 31 Dec. 1962. 32 pp. Signal Corps Contract DA-36-039 SC-89202

A successful data gathering trip into Central America yielded a large volume of rainfall information. This included daily, monthly, and annual data for a large number of stations. Statistical analysis of the monthly data for El Salvador has been initiated. Meso-scale analysis of daily rainfall is attempted.

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